United States Department of Agriculture

Forest Service

March 2013

Final

Environmental Impact Statement

Volume 2 of 2

Jack Rabbit to Big Sky Meadow Village 161 kV Transmission Line Upgrade

Bozeman Ranger District, Gallatin National Forest
Gallatin County, Montana

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UNDERGROUND ALTERNATIVE

INTRODUCTION

Several comments were received from the public during scoping requesting the consideration to install the transmission line underground. The following discussion addresses underground technologies, construction practices, maintenance requirements, reliability issues, cost and environmental impacts, that when considered in total make undergrounding of transmission lines impractical except for short distances generally in congested metropolitan and suburban areas.

High voltage underground 230 kV and some 345 kV transmission lines are now being used in large North American metropolitan cities like San Francisco, New York, or Vancouver BC where the lines are placed in large tunnels underneath the streets of these highly congested cities that have no space available for overhead lines. Lower voltage transmission lines (69 kV through 161 kV) occur over short distances in the United States primarily in congested urban areas. Because underground lines are less reliable than overhead lines due to longer outages, multiple parallel lines are often needed so power is not disturbed to the area where a problem or outage occurs with one of the lines. This need for redundancy increases the cost of burying transmission lines.

Underground transmission lines have markedly different technological requirements than overhead transmission lines. Overhead conductors are cooled by the open air surrounding them. Placing the conductors on towers puts these conduits of energy above most human activity on the ground in a transmission corridor and deals effectively with the issue of heat. Underground transmission lines require cooling systems to dissipate the heat generated by the transmission of electricity. The high cost of large cooling systems make underground lines very expensive, and other special design requirements prohibit the application of underground transmission systems for long distance electric transmission. Cooling system technology is discussed below.

Cost to Underground

One major reason why utilities do not normally install long distance transmission lines underground in rural areas is that the construction and operation costs of an underground transmission line are many times more expensive than the cost of overhead construction and operation. Depending on topography, costs for an underground 69 kV to 161 kV cable typically range from five to ten times greater than construction of overhead lines in open country with reasonable access and gentle terrain. Cost can quickly exceed ten times and up to 20 times those of overhead transmission in areas with limited access and rough terrain.

NorthWestern Energy (NorthWestern) is a regulated utility that is required to provide reasonable need and justification for rate based recovery of cost associated with their capital projects within their electrical system. Rate increase requests are reviewed and approved by the Public Service Commission (PSC) of Montana. In the event the PSC does not approve rate based recovery for costs associated with electrical system improvements, NorthWestern is faced with: 1) burdening the cost; 2) developing a reasonable cost effective solution that is not deemed excessive from PSC's stand point; or 3) requiring the end user to incur the costs.

Distribution underground is more common in subdivisions and urban areas where costs are included in development and passed on to the consumer. Individuals, groups, or communities that have the ability to generate revenue to cover the costs associated with added service such as buried distribution lines would be required to work with NorthWestern to negotiate their desire and feasibility of the added services associated with underground distribution.

Reliability Concerns

While underground transmission lines are relatively immune to weather conditions, they are vulnerable to washouts, seismic events, cooling system failures, and inadvertent excavation. Other possible causes for cable failure include water intrusion into the cable, overheating of the cable, high voltage transients (spikes in voltage), thermal movement during load cycling, and aging of the cable. The repair of underground cable systems has relatively long outage times compared to repairs of traditional overhead lines.

When a fault occurs the circuit is out of service and may not be placed back into service until repair and testing of the system is completed. Because the cable contains a central hollow duct in the conductor that carries cooling dielectric fluid, outage levels can be lengthy until fluid levels are restored. Qualified cable-splicing personnel may be difficult to retain on short notice. It can take one to two weeks to mobilize qualified technicians and equipment to splice a failed cable. The estimated minimum outage duration for locating, excavating and repairing a single cable failure is estimated to be at least three weeks and upwards of months. Typically, failures in overhead lines can be located and repaired in a matter of hours.

Long-term outages would be unacceptable for a circuit carrying power to end user the utility is regulated to supply with reliable service. Further, an underground conductor may last only 10 years, whereas an overhead line can last as long as 50 years.

Reactive Power Compensation

Other electrical problems, referred to as capacitive characteristics, can be a problem for underground systems. The capacitive reactive loads for this project are estimated to require above ground compensation stations located every seven to 20 miles along the transmission line route. A further consideration is that the line across this distance may not be capable of reliably accommodating these very significant reactive power loads, furthermore diminishing the feasibility of this alternative.

Environmental Concerns

The environmental impacts of constructing an underground transmission line would be similar to those for major pipeline construction. Typical construction would involve continuous trenching and associated ground disturbance for the entire distance. Trenching would be done for a width of 15 to 20 feet wide, and four-feet in depth through the difficult terrain of the Gallatin Canyon, not impossible, but highly impractical due to steep slopes, instability, and traffic and worker safety.

Areas that require concrete vault installation to accommodate the underground transmission line would exceed the normal disturbance width significantly. Crossing the Gallatin River would require boring under the river four to six feet below the river bottom. Whereas an overhead transmission line construction would have the flexibility to span sensitive natural and land use features, an underground line would need to trench through or bore under resources to avoid them.

Underground Technologies

There are four basic underground cable technologies for underground circuits:

- Solid Dielectric (Cross-Linked Polyethylene or XLPE)
- Gas Insulated Transmission Line (GIL)
- Pipe-type (High Pressure Fluid Filled or HPFF)
- Self-Contained Fluid Filled (SCFF)

Solid Dielectric Cable

The components of a typical solid dielectric cable are shown in Figure 1. The typical cable consists of a stranded copper or aluminum conductor, semi-conducting extruded conductor shield, extruded dielectric insulation, extruded semiconducting insulation shield, a lead, aluminum, copper or stainless steel sheath moisture barrier, and a protective jacket. A metallic shield, tape or drainwire, is required to carry fault current when a sheath is not used. Newer cable technology uses a high voltage extruded dielectric insulation of XLPE. Applications of XPLE are limited to short transmission line distances. Generally solid dielectric technologies are used for lower voltage underground transmission lines that carry less current.

Gas Insulated Transmission Line

Gas Insulated Line (GIL) technology at 161 kV and higher voltage levels has been implemented primarily within substations and not for longer transmission lines. GIL has been incorporated into substation designs with the length typically limited to distances less than 1,000 feet. The high cost and lack of experience with respect to longer underground transmission lines, and questions of reliability are more of a concern that other more prominent cable technologies.

High Pressure Fluid Filled Cable

High pressure fluid-filled (HPFF) cable systems are a pipe-type system where three single phase cables are located within a single steel pipe (see Figure 2). HPFF cables use Kraft paper insulation or a laminated polypropylene paper (LPP) insulation that is impregnated with dielectric fluid to minimize the insulation breakdown under electrical stress.

Since the system requires a continuous high pressure, pumping plants are required every seven to ten miles along the route, assuming a relatively flat topography. The pumping plants are responsible for maintaining a constant pressure on the system, but must have large reserve tanks to facilitate the expansion and contraction of the dielectric fluid as the system undergoes thermal cycling.

To maintain an operable pipe-type system, cathodic protection must be applied to the cable pipes to mitigate corrosion. This in turn helps prevent fluid leaks which pose both an operational and an environmental concern. If a loss of coolant fluids were to occur it would result in environmentally hazardous coolant materials contaminating the surrounding soil and aquatic resources in the Gallatin Canyon. A coolant fluid leak can be caused by several means including thermal expansion and contraction of the cable due to power cycling, ground movement, splice breakage, termination movement, improper installation, and a cable fault. The fluid is under pressure, if a leak occurs it can spread.

Using an HPFF system can provide high reliability, but requires additional equipment, resulting in additional opportunity for component failure, while specially trained personnel, who are typically located outside of NorthWestern's service territory, would be required to maintain these systems.

Figure 1 Solid Dielectric Cable

Figure 2 HPFF Pipe Installation

Self Contained Fluid Filled Cable

Self-contained fluid filled (SCFF) cable systems are very similar to the HPFF systems. The cable is typically constructed around a hollow tube, used for fluid circulation, and uses the same Kraft paper or LPP insulation materials. Because the fluid system is "self-contained" the volume of fluid required is significantly less, however, the same distribution of pumping plants as in HPFF systems would be required. While SCFF cable systems have the longest running history at the extra high voltage levels, their use is typically restrained to long submarine cable installations.

Superconducting Cables

Research is currently underway in the advancement of high temperature superconductors (HTS). Utilizing a unique cable design where all three phases are centered concentrically on a single core, the cables are capable of displaying low electric losses with the same power transfer capabilities as compared with a standard non-superconducting cable (see Figure 3). The core, filled with a cryogenic fluid, super cools the conducting material resulting in extremely low losses and high electrical power transfer capacities. Most HTS systems are located adjacent to large metro areas, where they are capable of transferring large quantities of power a few thousand feet away, at the distribution level. However, technological advances in the last few years have seen the first 138 kV system installed in Long Island, New York in early 2008. Because HTS systems have not been established at the 161 kV voltage levels, superconducting cable would not be a technology option unless further technology is developed.

Figure 3 HTS Superconducting Cable Design

Design of Underground Cable Systems

The following are key considerations for underground transmission line design of a 161 kV cable system:

- A 161 kV cable system would consist of multiple cables per phase to achieve the target power transfer requirements and to provide redundancy in the case of a cable failure.
- Concrete encased duct banks would be installed at a minimum cover depth of three feet, or as required by routing design, and would be backfilled with specially engineered thermally favorable backfill to assist in heat dissipation.
- To obtain further redundency, multiple duct banks per circuit can be utilized to minimize same mode failures of the systems.
- Dependent upon installation location, a permanent access road approximately 14 feet in width would be required to perform operation and maintenance procedures.
- The total construction surface impact of the underground cable system is at a minimum approximately 30 to 50 feet, and includes any permanent access roads.
- Splicing of the cable would be required approximately every 1,500 to 2,000 feet. Splicing would be performed inside large underground vault structures. Vault dimensions would be approximately 12 feet wide, by 28 to 40 feet long, by eight to nine feet deep, dependent upon the cable manufacturer splice and cable racking requirements.
- Depending on the terrain characteristics, burial depths may need to be increased to avoid heating the soil and changing the conditions of the vegetation and wildlife habitat above the duct bank or pipe type cables.
- Underground to overhead transition stations would be required at each end of the underground transmission line, and at each intermediate reactive compensation and pumping stations. Requiring two to four acres, each site would consist of pedestal type termination structures, reactors (similar to a large power transformer in appearance), and pumping plants, dependent upon cable system. In addition to these structures, A-frame dead-end structures, approximately 80 foot tall, would be required at each end of the system.
- Underground to overhead transitions at the 161 kV level can be accomplished with a single steel structure design if a solid dielectric cable system is implemented.
- Pumping plants would be required every seven to ten miles along the route, HPFF or SCFF cable systems.

- Reactive compensation would be required every seven to 20 miles along the route to offset the capacitive reactance of the cable system.
- The 12.5 kV distribution circuit would typically remain overhead adjacent to the underground ROW.

Reliability and Maintenance

Basic maintenance of the above cable systems consists of a thorough yearly inspection, while any fluid systems must be inspected and tested monthly. Inspections include all terminations and splices, all bonding systems, as well as all valves, gauges, switches, and alarms within the pumping plant. Cathodic protection systems are monitored as an on-going process.

Long-term reliability of underground cable systems is a major concern. A catastrophic failure of any portion of the system (cable, splices, terminations, or fluid systems), could result in the cable system being inoperable and out of service. While overhead lines can quickly be visually inspected for damage, underground lines must be tested with specialized equipment to locate the damaged cable or system components. Upon locating the failure, highly trained workers must be mobilized to repair or replace the faulty equipment or cable, resulting in outages lasting several weeks to months. The forced outage, as well as the extensive repair time, may result in increased stress to the remaining electrical grid.

Construction Process

Large open trench installation or the more costly trenchless technologies are utilized to place the cables underground. Construction includes, but may not be limited to clearing of the ROW, trenching, installation of duct banks or pipe networks, installation of vaults, cable splicing and terminating, and termination structure construction.

Trenching

Generally the most common technique for placing underground lines, open cut trenching utilizes a large surface excavation to place the required infrastructure (see Figure 4). The typical trench dimensions vary by cable type, voltage level, and required power transfer, but in all cases require a minimum cover depth of three feet with a typical trench being four feet in depth. Typical Trenching requirements would likely be 15 to 20 wide and four-feet in depth through the Gallatin Canyon with a construction ROW to support construction equipment necessary to support the excavation of 50 to 100 feet depending on the terrain. Areas that require concrete vault installation for the underground facilities would exceed the trench requirements and increase the construction ROW for trenching described above.

While a number of cable arrangements can be achieved, soil characteristics and existing infrastructure often play the largest role of how the installations are designed. Trenching operations are typically staged such that a maximum of 300 to 500 feet of trench is open at any one time. Steel plating may be positioned over the open trench to minimize surface disruptions, while traffic controls alleviate congestion through the project area. Emergency vehicle and local access must be coordinated with local jurisdictions as necessary.

Duct Bank Installation

Typical single and double circuit solid dielectric cable system duct bank configurations for underground transmission lines is shown in Figure 5, while Figure 6 shows a typical pipe type cable system configuration. The cable duct diameter is derived from the intended cable size, leaving approximately 50% of the conduit space to open air. Often ducts for communications or a continuity conductor are included within the concrete encasement.

Pipe type cable systems use steel pipes to encase each set of cables. Pipe type cable systems can be utilized at the 161 kV voltage level. The steel pipe acts as a means for grounding and fluid containment, as well as physical protection for the cable. One complication to the pipe type system is the requirement of cathodic protection to keep the steel pipe from corroding. In both installations specialized backfill known as fluidized thermal backfill (FTB) may be utilized. FTB is engineered with a specific thermal resistivity to assist in heat dissipation of the cable system, thus increasing the maximum continuous power transfer.

Figure 4 Typical 161 kV Solid Dielectric Duct Bank Installation

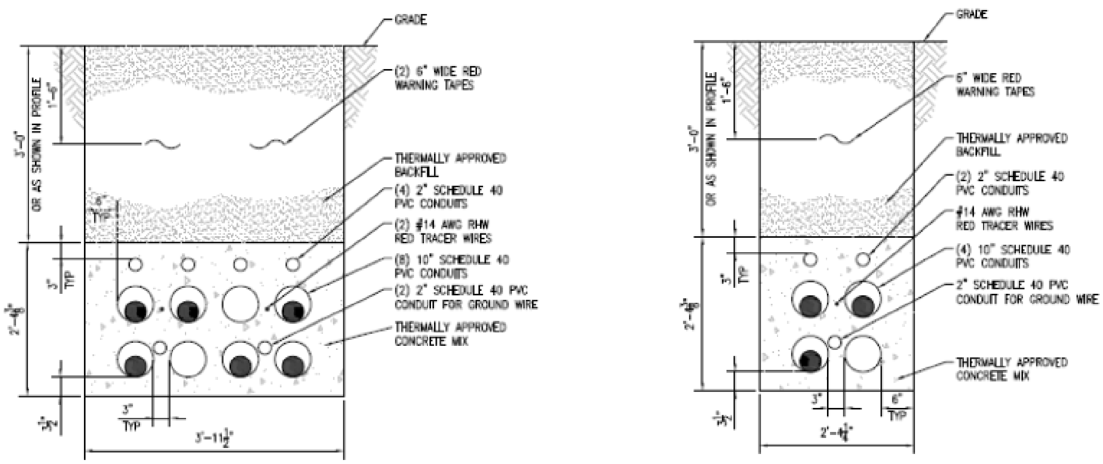

Figure 5 Typical 161 kV Solid Dielectric Duct Bank Configuration

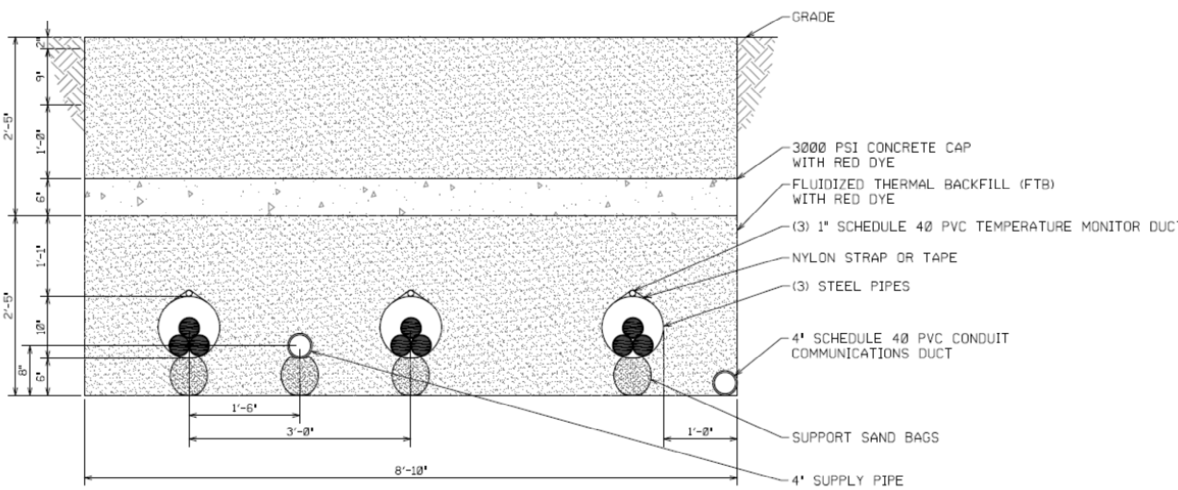

Figure 6 Typical Pipe Type Configuration

Vault Installation

Preformed concrete splice vaults are placed at approximately 1,500 to 2,000 foot intervals depending on the maximum cable per reel length. The vaults, initially used to install the cables into the conduits, are primarily used to house the splice assemblies, and to provide access for yearly inspections of the system. The vaults are used to sectionalize segments of cable in the event of a failure to locate the faulted cable and repair the required section. The typical installation time frame of each vault is approximately one week beginning with excavation, placement, compaction, and finally resurfacing of the excavated area (see Figure 7).

Cable Pulling, Splicing, and Termination

Upon completion of the civil construction, cables are installed within the duct banks or steel pipes. Each cable segment is installed, spliced at each of the vaults along the route, and terminated at the transition sites where the cable connects to overhead conductors. To install the cable, a reel of cable is positioned at one end of a cable section, while a pulling rig is located at the other end. Using wire rope, each section of cable is installed into its respective conduit/steel pipe, while workers apply either water based lubricant for solid dielectric cable or dielectric fluid for pipe type cable, to the cable jacket to minimize the frictional forces placed on the cables. Before termination or splicing operations begin, the cables are trained into the correct position using heat blankets. This process removes the curvature of the cable from being on the reel while also relieving any longitudinal strain exerted on the cable during pulling operations.

Termination Structure Construction

Dependent upon the cable technology used, at the 161 kV voltage level either single structure transitions or larger transitions sites, resembling those of larger transmission lines, are required. Typical transition sites house an A-frame style dead-end structure with pedestal style termination structures. Pipe type cable systems must also incorporate a pumping plant, fluid reservoir, and cathodic protection equipment. Because of the size requirements of each site, approximately 90 feet by 60 feet, a full ground grid, meeting all applicable codes for step and touch potentials, would also be required.

Figure 7 Typical HPFF Vault Installation

Special Construction Methods

In locations where open trench construction is not feasible, such as water crossings, congested roadway crossings, methods of trenchless installation must be utilized. Three main types of trenchless technologies exist. These are:

- Jack and Bore Tunneling (J&B)
- Horizontal Directional Drilling (HDD)
- Microtunneling

Jack and Bore Tunneling - J&B is an auguring operation that simultaneously jacks or pushes a steel casing into the excavated cavity (see Figure 8). As the equipment progresses forward, subsequent casing segments are added, while the spoils are removed through the center of the casing. Upon completing the crossing, the duct system is positioned inside of the steel casing using specially designed spacers, and the entire casing is then backfilled with thermally designed grout. The grout not only solidifies the installation from any movement, but also helps dissipate heat away from the cable system. For pipe type cable systems, the jacked casing can double as the cable pipe and may be welded to the trenched cable pipe.

Horizontal Directional Drilling -The HDD method uses a steerable cutting head to create a pilot hole along a predetermined route. Using progressively larger reamers, the hole is enlarged to the intended diameter. A product casing is then pulled through the hole and duct work, using specially designed spacers, is positioned within the casing. Grout is pumped into the voids within the casing to secure the installation and assist with the thermal transfer of heat away from the cable system. As with the J&B method, the casing can be used as the cable pipe in a pipe type cable system.

Microtunneling - Microtunneling resembles the J&B method, however the casing diameters and distances can typically be increased. Microtunneling uses a remotely operated tunneling machine to create the desired diameter hole. A casing is then placed into the excavated hole and duct work is positioned within the casing. As before, the casing is filled with grout, or the casing can be used as the product pipe in a pipe type cable system.

Construction Time

Installing large segments of underground transmission lines can require as much as twice the construction time of overhead lines, if not more, due to the extensive excavation required to complete the trenching and installation of the system infrastructure. Furthermore, environmental and/or seasonal restrictions can limit construction time frames as well as rugged terrain and traffic congestion in the Gallatin Canyon further extending scheduling efforts.

Figure 8 Jack and Bore Installation

Conclusion

Underground cable system installation has historically been justifiable in terms of cost and reliability in urban or metropolitan areas, and for limited distances. Because of the high cost of an underground line as compared to overhead 161 kV transmission line, reliability and reactive compensation issues for long installations, increased land disturbance, and the impracticality of construction on mountainous terrain, the alternative of undergrounding was not considered feasible for the Project.

The reduction of long term visual impacts of underground versus overhead transmission does not outweigh the high cost, and technical and constructability challenges, reduced reliability and additional land disturbance and environmental impact associated with underground construction. Underground 161 kV is not capable of meeting the purpose and need for the project. Underground construction of the transmission line is not considered a viable alternative, and was eliminated from further consideration for the entire length of the project or for discrete segments.

Underground distribution faces similar challenges to those of transmission. Costs associated with underground would be incurred by the end user. Should this type of additional service be desired from individuals or groups, they would have to negotiate this with NorthWestern first and then take the appropriate action with the Forest Service if their land was involved.